

Fossil *Adulomya* (Vesicomysidae, Bivalvia) from Japan

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Abstract. The Cenozoic fossil record of the vesicomysid bivalve genus *Adulomya* in Japan is evaluated. Five of the nominal species are confirmed based on shell morphology, hinge dentition, and the shape of the pallial line. Two of these are new to science: *Adulomya hamuroi* sp. nov. from the uppermost lower or lowest middle Miocene Higashibessho Formation in Honshu, and *Adulomya kuroiwaensis* sp. nov. from the uppermost middle or lowest upper Miocene Ogaya Formation in Honshu. A well-preserved specimen of *Adulomya uchimuraensis*, the type species of *Adulomya*, shows that this species lacks a pallial sinus and has an elongate ovate posterior adductor muscle scar. We redescribe *Adulomya chitanii* based on well-preserved, newly collected material. The identity of specimens previously assigned to the latter two species is outlined. *Adulomya* appears to have dispersed during the early Miocene from western North America along the North Pacific continental slope to Japan. It is present with five species in early and middle Miocene strata of Japan and shows a steep decline in diversity through the late Miocene and Pliocene. This decline coincides with, and may thus be linked to, the appearance and diversification of the vesicomysid genera *Archivesica* and *Calyptogena* from the late Miocene onwards. In the waters around Japan today, species of *Adulomya* live in deeper water than other vesicomysids and might thus have followed the onshore–offshore trend as suggested for other members of the vent and seep fauna.

INTRODUCTION

Vesicomysid bivalves are among the more prominent members of the chemosynthetic deep-sea fauna and have been frequently recorded from the Cenozoic fossil record of Japan (Amano & Kanno, 2005; Majima et al., 2005). These species were described under various generic names including *Calyptogena* Dall, 1891; *Adulomya* Kuroda, 1931; *Akebiconcha* Kuroda, 1943; *Hubertschenckia* Takeda, 1953; and *Vesicomys* Dall, 1886 (Hatai & Nisiyama, 1952; Masuda & Noda, 1976; Nobuhara, 2003). A revised generic classification of vesicomysid bivalves from the North Pacific region has recently been established (Amano & Kiel, 2007). Accordingly, the large-sized vesicomysids in this region can be assigned to the following four genera: *Calyptogena*; *Archivesica* Dall, 1908; *Adulomya*; and *Hubertschenckia* (Table 1).

Among these, *Adulomya* includes elongate to very elongate shells with a very small or no pallial sinus, and with only two cardinal teeth in the right valve instead of three, as in most other vesicomysids. Fossil species in Japan include the long-known *Adulomya uchimuraensis* Kuroda, 1931, *Adulomya chitanii* Kanehara, 1937, and the recently established *Adulomya hokkaidoensis* Amano & Kiel, 2007. The former two names have

been assigned to many Mio-Pliocene specimens, often based merely on the general shell outline. Whereas the characteristics of *A. uchimuraensis* have been described in detail (Kanno et al., 1998), the features of *A. chitanii* are insufficiently known or have been confused with those of other species (e.g., the ‘ontogenetic change’ of Kanno, 1971). Based on newly collected material and investigations of museum material, we provide here a detailed description of *A. chitanii*, describe two new species of *Adulomya*, outline the status of other species described as or assignable to *Adulomya*, and discuss the evolutionary implications of our findings.

MATERIAL

New material was collected from four Miocene and Pliocene formations in Honshu (Figure 1). Specimens of the type species of *Adulomya*, *A. uchimuraensis*, were collected from isolated carbonate bodies embedded in black mudstone of the middle Miocene Bessho Formation at Akanuda in Nagano Prefecture (Figure 1, loc. 1).

New material of *A. chitanii* was collected from isolated carbonate bodies within the Taira Formation at Donosaku, Iwaki City, in Fukushima Prefecture (= loc. 8 of Aoki, 1954; Figure 1, loc. 2 herein). Aoki

Table 1
 Characteristics of the vesicomylid genera.
 + present; – absent; ± basically absent, but sometimes present.

Genus	Maximum size (mm)	Subumbonal pit*	Pallial sinus**	Elongate shell	3a tooth	Nymphal ridge
<i>Adulomya</i>	180	±	±	+	–	–
<i>Archivesica</i>	250	+	+	±	+	–
<i>Hubertschenckia</i>	75	+	+	–	+	+
<i>Calyptogena</i>	90	–	–	±	+	+

* Krylova & Sahling (2006) pointed out that *Ectenagena* (= *Adulomya*) has a subumbonal pit. However, other than *A. elongata*, this genus does not have a distinct subumbonal pit. Amano & Kiel (2007) mistakenly illustrated a subumbonal pit in *Calyptogena* of their fig. 5, but this genus does not have it.

** While Krylova & Sahling (2006) showed that *Ectenagena* (= *Adulomya*) lacks a pallial sinus, *A. phaseoliformis* and *A. chitanii* show a v-shaped pallial sinus as described in the text.

(1954) reported the vesicomylid *Vesicomya kawadai* from the same outcrops.

Elongate vesicomylids were collected from turbidite deposits of the uppermost lower or lowest middle Miocene Higashibessho Formation at Shimo-Sasahara (Figure 1, loc. 3), Toyama City, in Toyama Prefecture. Vesicomylid specimens from this locality had previously been described as *Calyptogena* sp., (Amano et al., 2001).

Further elongate vesicomylids were extracted from isolated carbonate bodies within the upper Miocene Ogaya Formation at Kuroiwa (Figure 1, loc. 4), Joetsu City in Niigata Prefecture. Vesicomylid specimens from this locality had previously been described as *Calyptogena* sp. B by Amano & Kanno (2005).

All newly collected material is housed in the Joetsu University of Education (JUE). In addition, we examined specimens identified as *A. uchimuraensis* from the lower Miocene Nabae Group at Muroto (Figure 1, loc. 5) in Kochi Prefecture, Shikoku, which are housed at the National Science Museum (NSM) (Matsumoto & Hirata, 1972); and specimens of '*Calyptogena*' *akanudaensis* Tanaka, 1959 from the middle Miocene Bessho Formation in Nagano Prefecture, housed at the Shinshu-Shinmachi Museum.

SYSTEMATIC DESCRIPTIONS

Family VESICOMYLIDAE Dall & Simpson, 1901

Genus *Adulomya* Kuroda, 1931

Type species: *Adulomya uchimuraensis* Kuroda, 1931, from the middle Miocene Bessho Formation, central Honshu, Japan.

Remarks: Kanno et al. (1998) redescribed the type species in detail. *Adulomya* is characterized by its elongate shape, having two radiating cardinal teeth in the right valve; a pallial sinus is lacking except for *A.*

chitanii and *Adulomya phaseoliformis* Metivier, Okutani & Ohta, 1986, where the pallial line starts from the central part of posterior adductor muscle scar and forms a v-shaped pallial sinus (see also Amano & Kiel, 2007). Some of these characters can also be found in the enigmatic genus *Pleurophopsis*. Its type species, however, is too poorly preserved to show all characters needed for a robust classification and should thus not be used (Kiel, 2007)

Adulomya uchimuraensis Kuroda, 1931

(Figure 2)

Adulomya uchimuraensis Kuroda, 1931:27–28, pl. 13, figs. 111–114; Tanaka, 1959:117–118, pl. 1, fig. 1–10; Tanaka, 1960:24–26, pl. 32, figs. 1–7.

Calyptogena (Adulomya) uchimuraensis Kuroda, Kanno & Tanaka in Kanno et al., 1998:20–22, figs. 7–8.

Calyptogena (Adulomya) uchimuraensis kurodai Kanno & Tanaka in Kanno et al., 1998:22–25, figs. 9–10.

Akebiconcha chitanii (Kanehara). Kanno & Ogawa, 1964:pl. 1, figs. 17–18.

? *Adulomya uchimuraensis* Kuroda. Hayashi & Miura, 1973:pl. 1, fig. 15.

non-Akebiconcha uchimuraensis Kuroda. Matsumoto & Hirata, 1972:755–757, pl. 1, figs. 1–8, pl. 2, figs. 1–2.

Type material: According to Hatai & Nisiyama (1952), the type material is housed in the Institute of Geology and Mineralogy, Faculty of Science, Hokkaido University. Their register numbers, however, are unknown.

Material examined: Twenty-seven specimens from loc. 1 were examined. Among them, five specimens are well preserved and were measured (Table 2).

Remarks: In their redescription of *A. uchimuraensis*, Kanno et al. (1998) described the pallial sinus and

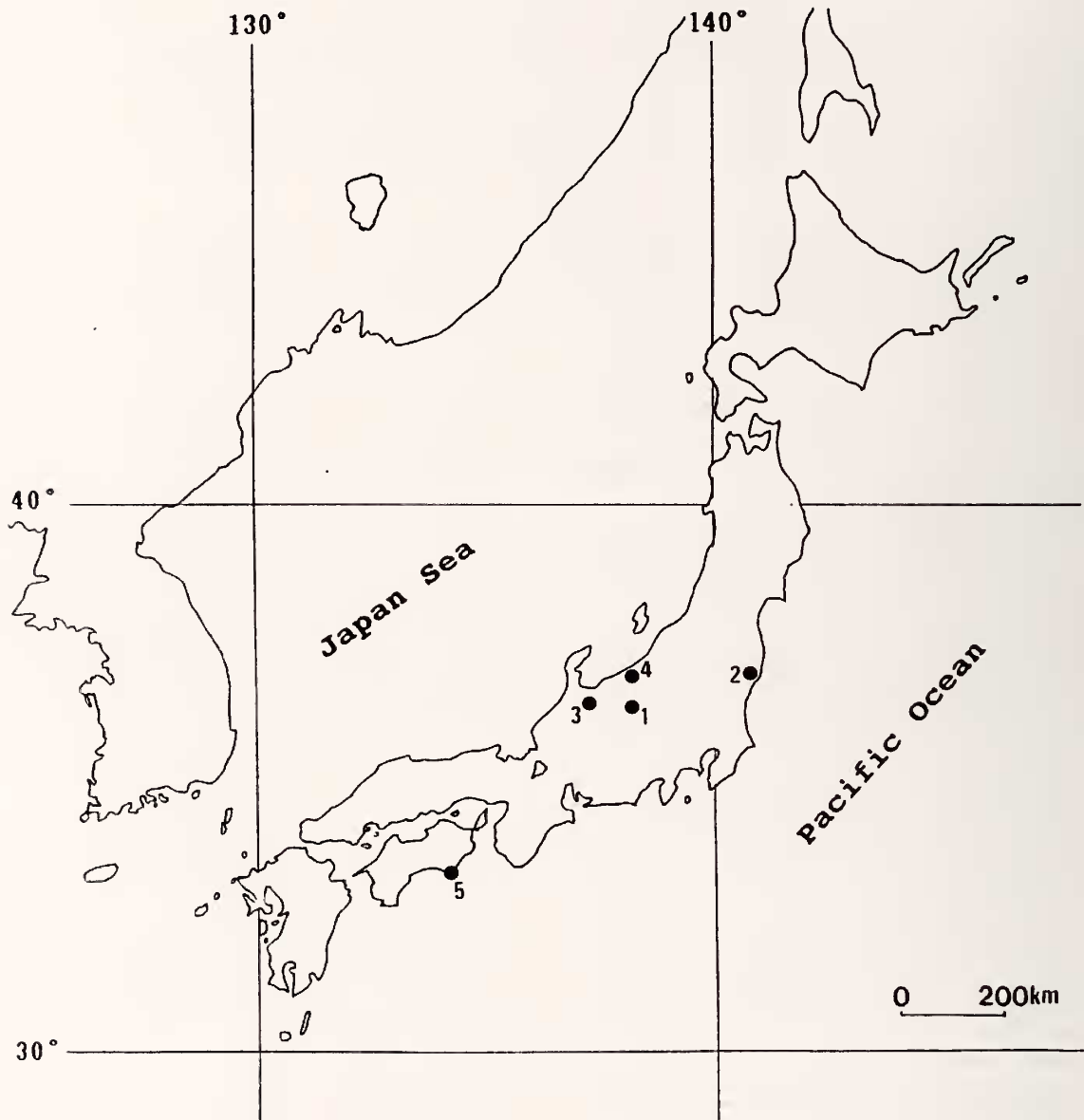


Figure 1. Locality maps of fossil specimens. Numbers of localities are shown in the text.

posterior adductor scar as indistinct and obscure, respectively. A newly collected well-preserved specimen (Figure 2) shows no pallial sinus and an elongate ovate posterior adductor muscle scar as present in most species of *Adulomya*. As already suggested by Amano & Kiel (2007), the subspecies *Calypptogena (Adulomya) uchimuraensis kurodai* Kanno & Tanaka in Kanno et al. (1998) is a synonym of *A. uchimuraensis*. According to Kanno et al. (1998) this “subspecies” differs from *A.*

uchimuraensis sensu strictu by having a straight ventral margin, and a higher and less convex shell. Our material does not show these differences in juvenile (= small) specimens, and we have transitional forms that are intermediate between the two putative subspecies.

Specimens that most likely belong to *A. uchimuraensis* were reported by Kanno & Ogawa (1964) as *Akebiconcha chitanii* from the lowest middle Miocene

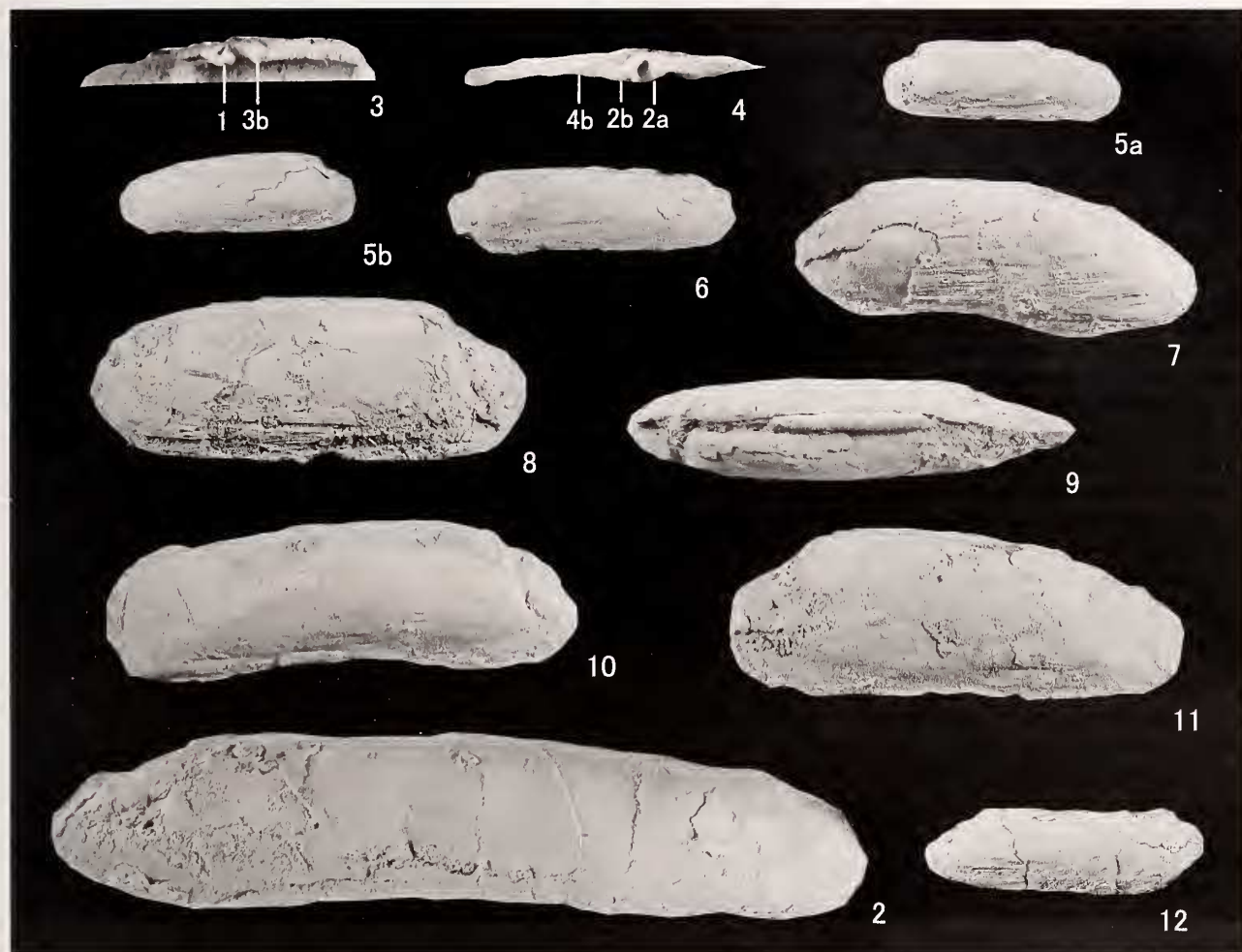


Figure 2. *Adulomya uchimuraensis* (Kuroda). Left valve showing the posterior adductor muscle scar and the entire pallial line; length 94.3 mm, JUE no. 15865-1, loc. 1.

Figures 3–12. *Adulomya chitanii* (Kanehara). All specimens are from loc. 2. Figure 3. Right-valve hinge, hinge length 15.4 mm, JUE no. 15866-29. Figure 4. Left-valve hinge, hinge length 19.4 mm, JUE no. 15866-30. Figures 5–6, 12. Outline of juvenile shells; Figure 5a,b, length 32.9 mm, JUE no. 15866-25; Figure 6, length 39.7 mm, JUE no. 15866-26; Figure 12, length 38.3 mm, JUE no. 15866-27. Figures 7–9. Outline of adult shells; Figure 7, length 55.5 mm, JUE no. 15866-23; Figure 8, length 61.0 mm, JUE no. 15866-8; Figure 9, dorsal view showing long external ligament, length 61.9 mm, JUE no. 15866-28. Figures 10–11. Pallial sinus of both valves; Figure 10, length 66.5 mm, JUE no. 15866-21; Figure 11, length 62.4 mm, JUE no. 15866-3.

Table 2
Measurements of *A. uchimuraensis*
(Kuroda) from loc. 1.

JUE specimen no.	Length (mm)	Height (mm)	Valve
15865-1	94.3	19.5	left
15865-2	91.3	20.9	left
15865-3	111.3	26.6	left
15865-4	120.5	27.5	right
15865-5	94.3	18.9	left

Takinoue Formation in Hokkaido. These specimens have longer and lower shells (length ca. 69 mm, height 16 mm) than *A. chitanii* and, in contrast to *A. chitanii*, lack a pallial sinus (see below).

Matsumoto & Hirata (1972) recorded *Akebiconcha uchimuraensis* from the Nabae Group in Shikoku. The age of the sediments was considered as late Oligocene, but recent micropaleontological work showed that they were deposited during the early Miocene (Iijima et al., 1981; Okamura & Taira, 1984; Suyari et al., 1989). The hinge dentition could not be investigated in any of the available specimens. However, specimens from the Nabae Group have an elongate shell with concave

ventral margin as shown in Figures 30 and 31. The largest specimen (i.e., Figure 31b) reaches 112.5 mm in length, has a distinct ridge just anterior to the ovate posterior adductor muscle scar, and lacks a pallial sinus. It might thus belong to *Adulomya*, although this needs to be confirmed by data on its hinge dentition. It differs from *A. uchimuraensis* by having a smaller and higher adult shell, a truncated anterior margin, and a deeply concave ventral margin unlike that of *A. uchimuraensis*.

Hayashi & Miura (1973) illustrated an elongate shell from the Miocene Okazaki Formation as *A. uchimuraensis*, but its hinge dentition and pallial line are unknown and thus its identity remains unclear.

Comparison: *Adulomya uchimuraensis* is similar to the Recent *A. phaseoliformis* in size and shell outline but differs by lacking a pallial sinus.

Distribution: Middle Miocene Bessho Formation in Nagano Prefecture and lowest middle Miocene Takinoue Formation in Hokkaido.

Paleobathymetry: Kanno et al. (1998) estimated that the sediments of the Bessho Formation at Akanuda were deposited in less than 200 m depth, based on the associated molluscan fossils. Kanno & Ogawa (1964) reported *Portlandia* cf. *tokunagai* and *Bathymalletia inermis* as the associated fauna of *A. chitanii* (= *A. uchimuraensis*) from the Takinoue Formation in Hokkaido. Extant members of these genera are found between the lower sublittoral and the middle bathyal zone (Higo et al., 1999). Thus, *A. uchimuraensis* most likely lived in this depth range, too.

Adulomya chitanii Kanehara, 1937

(Figures 3–12)

Adulomya chitanii Kanehara, 1937:19–20, pl. 5, figs. 1, 6–9; Kamada, 1962:39–41, pl. 1, figs. 4–7.

"*Adulomya*" *chitanii* Kanehara. Aoki, 1954:31–32, pl. 1, figs. 9–11.

Calyptogena chitanii (Kanehara). Kanno & Akatsu, 1972:pl. 8, figs. 13, 14; Amano & Little, 2005:figs. 6B, 6C, 6D; Amano & Jenkins, 2007:fig. 2C; Amano et al., 2007:figs. 3C, 3F, 3H.

Calyptogena sp., Yamaoka, 1993:pl. 4, figs. 1, 6, 7.

? *Calyptogena chitanii* (Kanehara). Shikama & Kase, 1976:pl. 2, fig. 6; Hirayama, 1973:175, pl. 15, fig. 12–13; Yamaoka, 1993:pl.4, figs. 2, 3.

? *Akebiconcha chitanii* (Kanehara). Hayashi & Miura, 1973:pl. 1, fig. 26; Hayashi, 1973: pl. 5, fig. 6.

non-Akebiconcha chitanii (Kanehara). Kanno & Ogawa, 1964:pl. 1, figs. 17–18; Kanno & Arai, 1964:pl. 1, figs. 19–22; Kanno, 1967:401–402, pl. 1, figs. 9–11, 15.

Table 3
Measurements of *A. chitanii*
(Kanehara) from loc. 2.

JUE specimen no.	Length (mm)	Height (mm)	Thickness (mm)
15866-1	70.4	21.0	13.7
15866-2	62.6	19.7	17.1
15866-3	62.4	21.8	14.7
15866-4	67.1	22.0	15.5
15866-5	61.7	19.6	14.2
15866-6	63.1	20.2	17.1
15866-7	57.9	17.0	11.5
15866-8	61.0	22.2	14.8
15866-9	67.1	21.1	13.6
15866-10	56.4	18.0	11.9
15866-11	58.8	19.5	17.0
15866-12	53.3	18.9	14.7
15866-13	55.2	18.7	14.2
15866-14	54.7	16.8	13.8
15866-15	53.3	19.8	12.8
15866-16	52.8	17.0	10.2
15866-17	54.3	17.1	10.5
15866-18	43.9	14.5	10.1
15866-19	48.6	14.9	9.0
15866-20	45.1	15.2	10.1
15866-21	66.5	19.8	14.0
15866-22	60.6	19.0	15.8
15866-23	55.5	17.9	—
15866-24	66.3	22.5	—
15866-25	32.9	10.6	5.9
15866-26	39.7	11.9	8.1
15866-27	38.3	11.4	7.4
15866-28	61.9	21.3	—

non-Calyptogena chitanii (Kanehara). Kanno, 1971:80–82, pl. 7, figs. 5–6.

Type material: Kanehara's (1937) type material from the Mizunoya Formation was destroyed during World War II (Hatai and Nisiyama, 1952; Kamada, 1962) and a neotype has never been assigned. Here we designate the specimen illustrated by Kamada (1962:pl. 1 fig. 4 = Amano & Jenkins, 2007:fig. 2C) stored at Institute of Geology and Paleontology, Tohoku University (IGPS no. 87339) as neotype.

Material examined: Twenty-seven well-preserved specimens from loc. 2 (Table 3) and the four specimens illustrated by Kamada (1962).

Supplementary description: Shell small for genus, up to 70.4 mm long, thin-walled, elongate throughout ontogeny (height/length ratio = 0.29–0.37), equivalve and inequilateral, weakly inflated, sculptured only by growth lines. Beak prosogyrate, situated at anterior one-eighth of shell length in juvenile specimens and at one-fifth in adults. Anterodorsal margin broadly arched, graduating into narrowly rounded anterior margin; ventral margin straight or slightly concave;

posterodorsal margin nearly straight, parallel to ventral margin, graduating into rounded posterior margin. Escutcheon and lunule absent; ligament exterior, strong and long, occupying three-fifths of posterodorsal margin.

Hinge plate narrow, with two cardinals in right valve and three cardinals in left valve. Right valve hinge: anterior cardinal tooth (3a) reduced; posterior cardinal tooth (3b) slightly bifid, oblique posteriorly; central tooth (1) thin, vertical to hinge base; subumbonal pit absent. Left valve hinge: anterior tooth (2a) thin, slightly oblique anteriorly, connected to stout middle tooth (2b); posterior tooth (4b) thin, oblique posteriorly; subumbonal pit absent. Nymph distinct and long, occupying two-thirds of the posterodorsal margin.

Anterior adductor muscle scar subcircular; posterior one ovate; pallial sinus very shallow and v-shaped; distinct inner ridge running from just under the posterior muscle scar to umbo; radial interior indistinct.

Remarks: There are numerous records of *A. chitanii* from lower to middle Miocene strata in Japan and Alaska. Many of these identifications are based only on external morphology and their identity is doubtful. This concerns records (as *Calyptogena chitanii* or *Akebiconcha chitanii*) from the Morozaki Group by Shikama & Kase (1976) and Yamaoka (1993), from the Okazaki Formation by Hayashi & Miura (1973), from the Ohno Formation in Aichi Prefecture by Hayashi (1973), and from the Hiranita Formation in Saitama Prefecture by Hirayama (1973).

In addition to the insufficient original description of Kanehara (1937), Kanno (1971) presented a scheme of the ontogenetic morphological change of this species that we are unable to confirm and that might have led to further confusion: elongate-ovate specimens described from the Itsukaichimachi Group in Tokyo Prefecture by Kanno & Arai (1964) and Kanno (1967) were considered juvenile forms, and Kanno's (1971) Alaskan specimens with large elongate shells and a concave ventral margin were considered adults (Kanno, 1971:text, fig. 11). Our observations of *A. chitanii* from loc. 2, however, indicate that juveniles and adults of *A. chitanii* have very similar proportions and the ventral margin is not as strongly concave as in the Alaskan specimens figured by Kanno (1971:pl. 7, fig. 6). Considering its two cardinal teeth and elongate shape, Kanno's Alaskan species belongs to *Adulomya* but not to *A. chitanii* (see also Kiel and Amano, 2010). Masuda & Noda (1976) suggested that specimens reported by Kanno & Arai (1964) and Kanno (1967) from the Itsukaichimachi Group belong to *Calyptogena pacifica*. However, the illustration of a right valve (Kanno & Arai, 1964:pl. 1, fig. 22; Kanno, 1967:pl. 1, fig. 15) shows two small cardinal teeth whereas *Calyptogena pacifica* has three. The specimens from the Itsukaichi-

machi Group might thus belong to *Adulomya*, but can currently not be assigned to any known species.

Comparison: *Adulomya chitanii* and *A. uchimuraensis* have been confused in the past, but can be easily distinguished by the lack of a pallial sinus in *A. uchimuraensis*, whereas it is present in *A. chitanii*. In addition, *A. uchimuraensis* grew to about 180 mm in length and has lower shell (height/length ratio = 0.12–0.26) whereas the maximum size of *A. chitanii* is about 70 mm and its height/length ratio ranges from 0.29 to 0.37.

Distribution: Lower Miocene Mizunoya, Kamenoo, and Taira Formations in Fukushima Prefecture; lower Miocene Toyohama Formation of Morozaki Group in Aichi Prefecture; middle Miocene Nupinai Formation in eastern Hokkaido.

Paleobathymetry: Taketani et al. (1990) used foraminifera to estimate that the Mizunoya, Kamenoo, and Taira formations were deposited in sublittoral to middle bathyal depth. The depositional depth of the Morozaki Group was estimated to range from 100 to 600 m by Shikama & Kase (1976). From the Nupinai Formation, Kanno & Akatsu (1972) listed *Portlandia*, *Nuculana*, *Periploma*, *Turritella*, and *Olivella*; based on the bathymetric range of living members of these genera (cf. Higo et al., 1999), the Nupinai Formation was deposited between the lower sublittoral and the upper bathyal zone. Thus, the bathymetric range of *A. chitanii* was probably from the lower sublittoral to the middle bathyal zone.

Adulomya hokkaidoensis Amano & Kiel, 2007

Calyptogena sp., Amano & Little, 2005:figs. 5 A, E, F.
Adulomya hokkaidoensis Amano & Kiel, 2007:278, figs. 13–18.

Type material: JUE no. 15848 (holotype) and JUE no. 15849 and 15850 (paratype) from the lower middle Miocene Chikubetsu Formation (upper part) in northwestern Hokkaido.

Distribution: Known only from the whale-fall community at the type locality.

Paleobathymetry: Benthic foraminifera suggest that *A. hokkaidoensis* lived at depth below the middle bathyal zone (cf. Maiya et al., 1982).

Adulomya hamuroi Amano & Kiel, sp. nov.

(Figures 13–17)

Calyptogena sp., Amano et al., 2001:192, 194, figs. 6–7, 12–14.

Diagnosis: A medium-sized *Adulomya* with elongate trapezoidal or elliptical shell having a concave ventral margin, and sculptured by fine growth lines. Right valve with two cardinal teeth: a stout and bifid posterior cardinal (3b) and an anterior cardinal (1) perpendicular to hinge base; no subumbonal pit; left valve with three cardinal teeth: short anterior cardinal (2a), stout and posteriorly oblique central cardinal (2b), and thin and long posterior cardinal (4b).

Holotype: Length 49.9 mm, height 23.3 mm, JUE no. 15857.

Paratypes: Length 36.3 mm, height 24.4 mm, JUE no. 15698-1; length 37.5 mm, height 26.6 mm, JUE no. 15698-2; length 59.2 mm, height 22.3 mm, JUE no. 15698-6.

Type locality: A large cliff about 250 m west of Shimosasahara, Yatsuo Town, in Toyama City, Toyama Prefecture; uppermost lower or lowest middle Miocene Higashibessho Formation.

Description: Shell thin, medium-sized (up to 59.2 mm in length), elongate-trapezoidal or elliptical, equivalve and inequilateral. Anterodorsal margin broadly arcuate; posterodorsal margin long, almost straight nearly parallel to ventral margin; ventral margin slightly concave in its central part. Beak very low, prosogyrate, and situated at anterior one-fifth of entire shell length. Surface sculptured by irregularly spaced growth lines; lunule absent; escutcheon not clearly demarcated. Nymph plate long and raised slightly above dorsal margin. Hinge plate narrow with two radiating teeth in each valve; no subumbonal pit. Right valve with strong, triangular anterior cardinal (1) starting below umbo and pointing downward, posterior cardinal (3b) equally strong, fused with anterior cardinal, bifurcating at posterior end, short, almost parallel to dorsal margin. Left valve with small anterior cardinal (2a) not reaching hinge base; central cardinal (2b) bifid with widely gaping edges; posterior cardinal (4b) long and thin. Both anterior and posterior muscle scars orbicular; distinct flexure running from beak to anteriormost part of posterior scar. Pallial line entire without sinus.

Remarks: Amano et al. (2001, p. 192) misinterpreted the right valve hinge as having three cardinal teeth. It has now become apparent that the "anterior cardinal tooth" is a ramp resulting from shell deformation. The "middle tooth" in their description corresponds to the real anterior one (1) which is perpendicular to the hinge base.

Comparison: Smaller specimens of *A. hamuroi* (Figure 13) have an elongate elliptical shell like *Calyptogena akanudaensis* Tanaka, 1959 (Figures 27–29 herein) from the middle Miocene Bessho Formation in Nagano

Prefecture. However, the present new species differs from *C. akanudaensis* by having a slightly higher shell with a concave ventral margin. Moreover, as the inner structure of *C. akanudaensis* is unknown, it is difficult to compare both species with each other in detail. *Adulomya kuroiwaensis* sp. nov. can be distinguished from *A. hamuroi* by having a larger shell, more anteriorly situated beak and more expanded posterior part.

Distribution: Known only from the type locality.

Paleobathymetry: *A. hamuroi* probably lived between the lower sublittoral and the upper bathyal zone, based on the associated molluscan fossils (Amano et al., 2004).

Etymology: After Mr. Toshikazu Hamuro (Imizu City, Toyama Prefecture), who collected and offered some well-preserved shells.

Adulomya kuroiwaensis Amano & Kiel, sp. nov.

(Figures 18–26)

Calyptogena sp., Ueda et al., 1995:figs. 4a–d.

Calyptogena sp. B, Amano & Kanno, 2005:208–209, figs. 8, 14–15. (non-:figs. 7, 10).

Adulomya n. sp., Amano et al., 2010; figs. 5G, H, M, O.

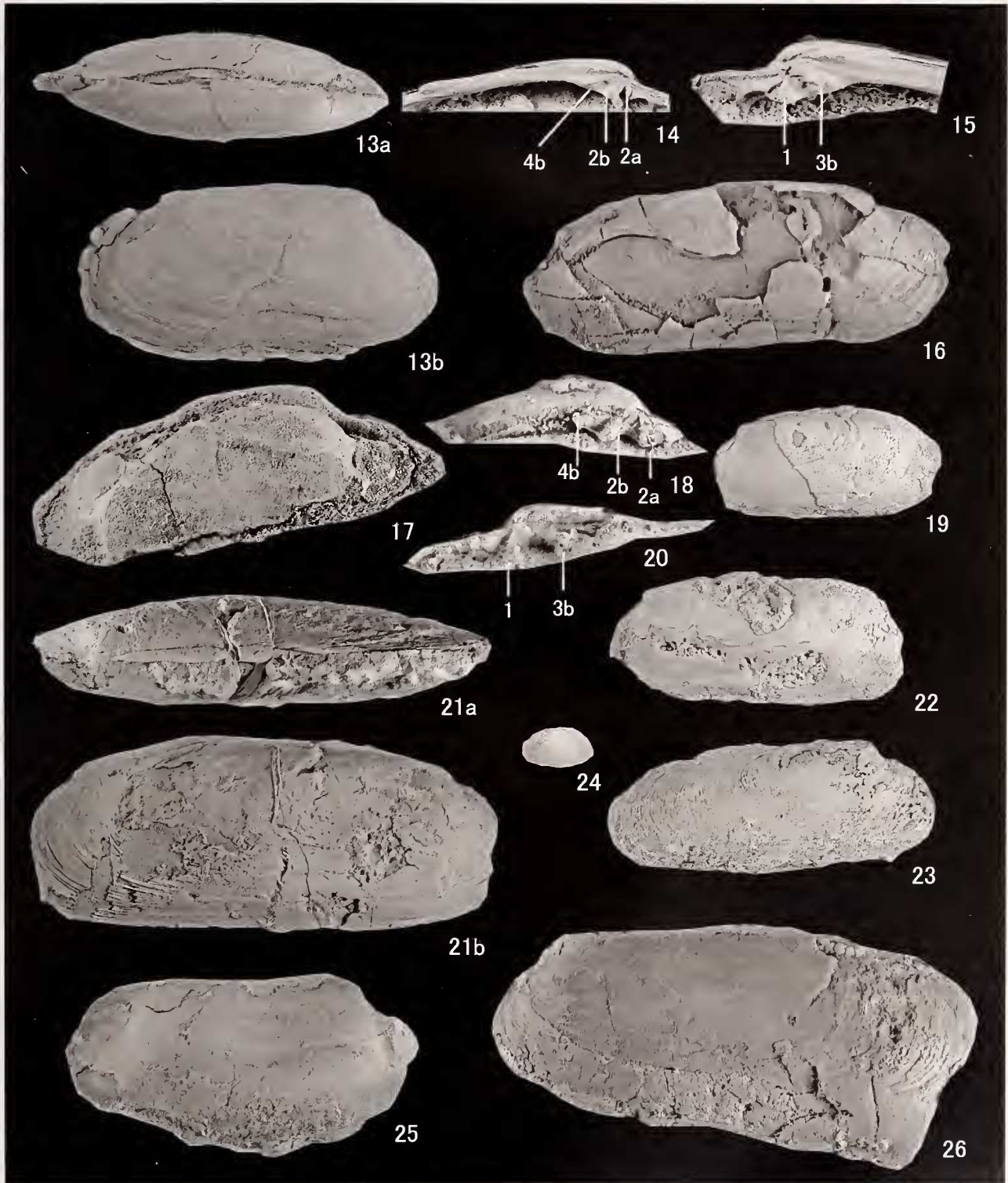
Diagnosis: A medium-sized *Adulomya* with elongate shell with anteriorly situated beak, rather straight ventral margin, expanded posterior part and no pallial sinus; two cardinal teeth in right valve; three cardinal teeth in left.

Holotype: Length 63.4 mm, height 24.8 mm, JUE no. 15858.

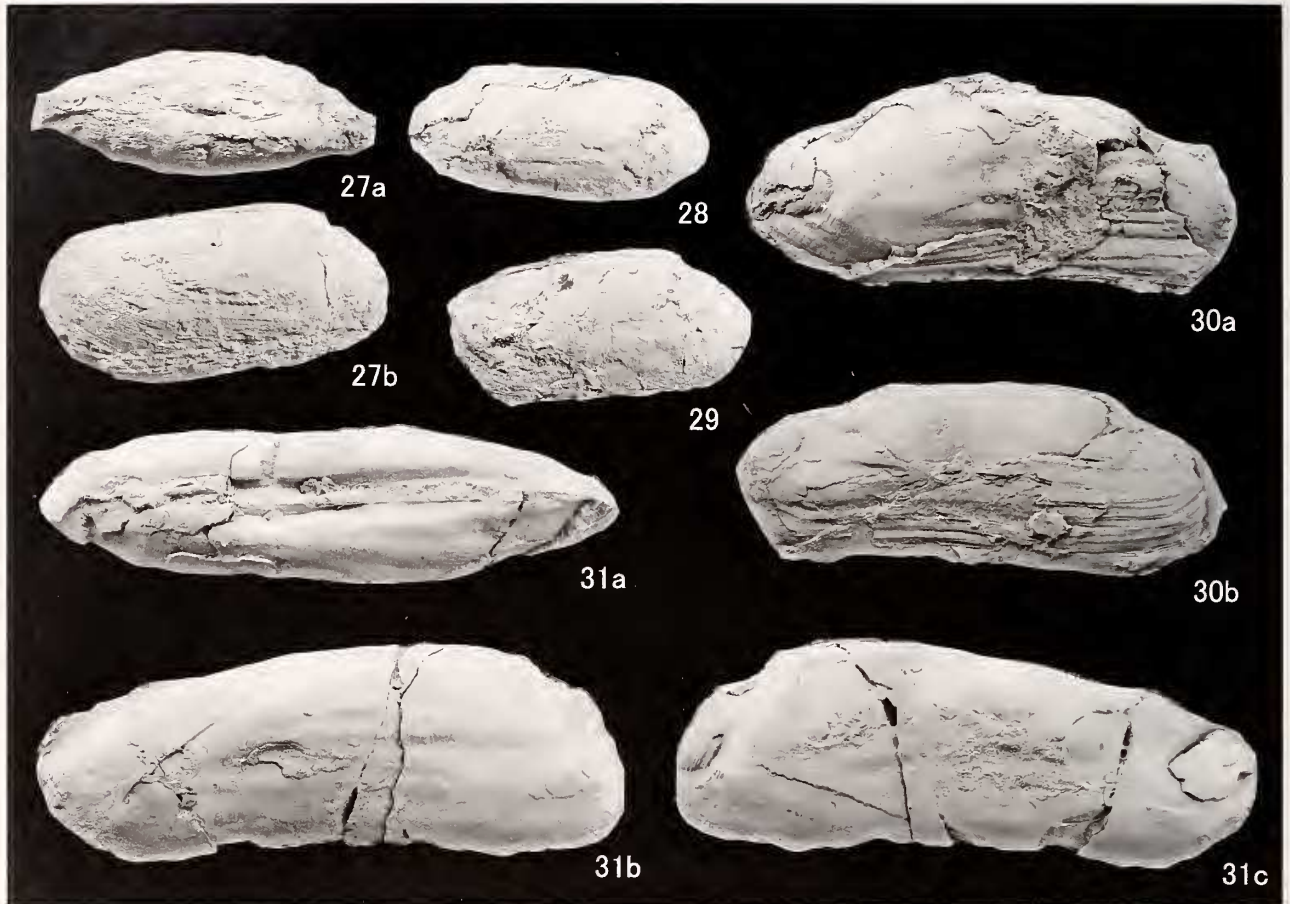
Paratypes: Length 66.7+ mm, height 24.6 mm, JUE no. 15859; length 43.6 mm, height 16.7 mm, JUE no. 15860; length 47.2 mm, height 22.1 mm, JUE no. 15861.

Type locality: There is a northern and a southern quarry at Kuroiwa in Joetsu City, Niigata Prefecture, where large carbonate bodies facing the road from Joetsu to Kashiwazaki are exposed. Of these, the southern quarry is the type locality of *Adulomya kuroiwaensis*. The exposed sediments belong to the uppermost middle or lowest upper Miocene Ogaya Formation.

Description: Shell medium in size, more than 89.1 mm long, thin-walled, elongate (height/length ratio = 0.34–0.55), posteriorly expanded, slightly inflated, equivalve and inequilateral. Surface sculptured by fine growth lines and few concentric ridges on posterior part of juvenile shell. Beak prosogyrate, situated at anterior one-eighth of entire shell length in adults and at



Figures 13–17. *Adulomya hamuroi* sp. nov. All specimens are from loc. 3. Figure 13a, b. Holotype, length 49.9 mm, JUE no. 15857. Figure 14. Left valve hinge of paratype, illustrated hinge length 31.0 mm, JUE no. 15698-3. Figure 15. Right valve hinge of paratype, illustrated hinge length 14.6 mm, JUE no. 15698-4. Figure 16. Outline of paratype, length 59.2 mm, JUE no. 15698-6. Figure 17. Paratype showing the entire pallial line and the posterior adductor scar, length 54.5 mm+, JUE no. 15698-5. Figures 18–26. *Adulomya kuoiwaensis* sp. nov. All specimens are from loc. 4. Figures 18, 20. Hinge of paratype; Figure 18, hinge



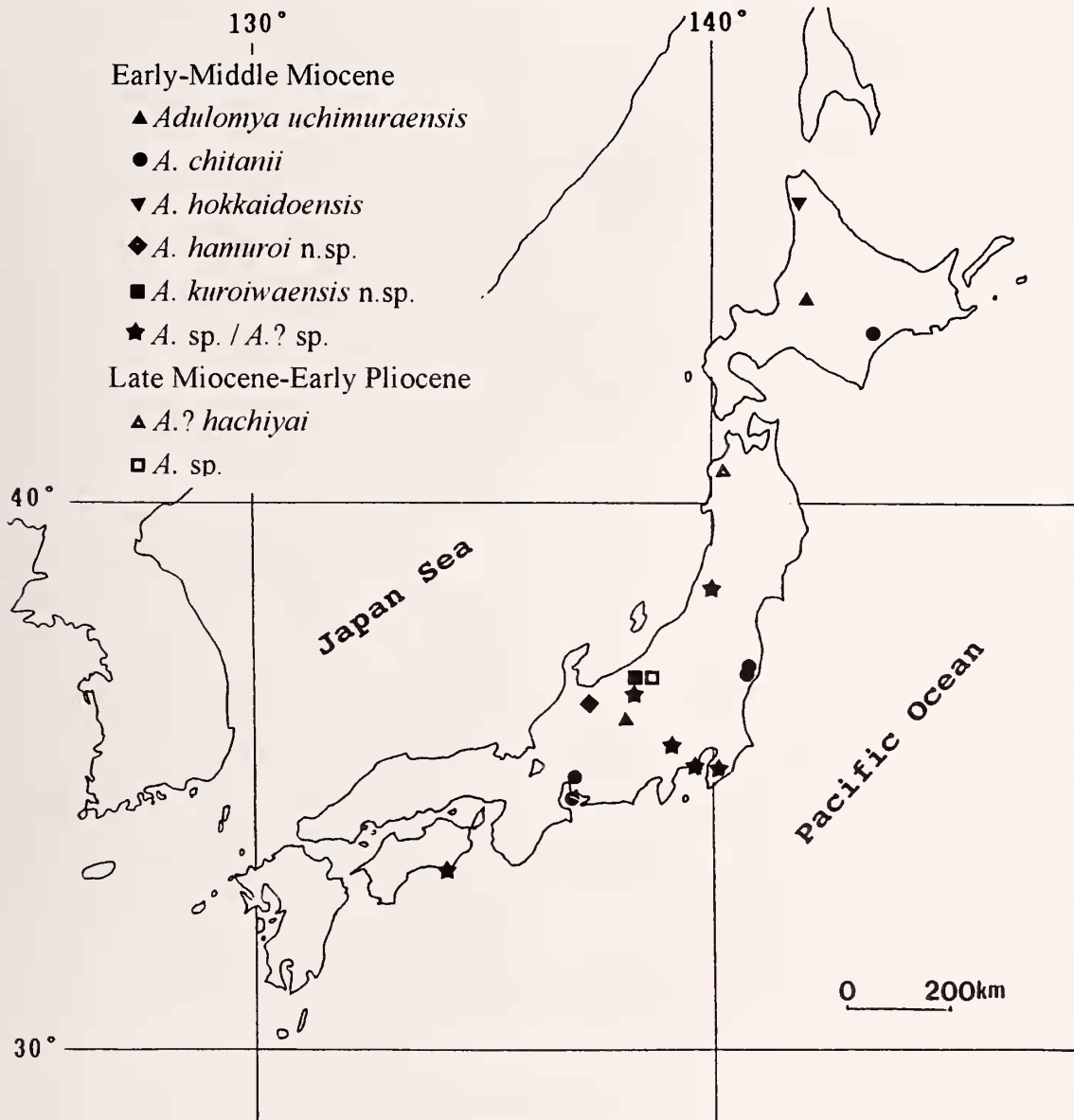
Figures 27–29. *Calyptogena akanudaensis* (Tanaka). Paratypes, loc. 1.; Figure 27a, b, length 55.7 mm, Reg. no. 426 of Tanaka (1959); Figure 28, length 43.4 mm, Reg. no. 424 of Tanaka (1959); Figure 29, length 56.2 mm, Reg. no. 425 of Tanaka (1959). Figures 30–31. *Akebiconcha uchimuraensis* (Kuroda) by Matsumoto & Hirata (1972) (= *Adulomya?* sp.), loc. 5. Figure 30a, b, outline of shell, length 93.1 mm+, NSM PM13227. Figure 31a, dorsal view showing very long external ligament; Figure 31b, right valve with entire pallial line; Figure 31c, left valve, showing deeply excavated anterior adductor scar; length, 112.5 mm+, NSM PM13228.

anterior one-sixth in juveniles. Ligament rather strong, occupying more than half of posterodorsal margin. Posterodorsal margin beneath ligament straight and horizontal, forming blunt angle with the broadly arcuate posterior half; posterior margin well rounded, graduating into ventral margin; ventral margin usually straight but concave centrally in gerontic specimen; anterodorsal margin short and broadly arcuate, graduating to narrowly rounded anterior margin. Lunule

and escutcheon absent. Hinge plate narrow with two cardinal teeth in right valve and three cardinal teeth in left valve. Subumbonal pit unknown. Right valve hinge: anterior cardinal tooth (3a) reduced; posterior cardinal tooth (3b) low, oblique posteriorly; central tooth (1) thin, perpendicular to hinge base. Left valve hinge: anterior cardinal tooth (2a) small, oblique anteriorly; middle tooth (2b) weakly bifid, slightly oblique posteriorly; posterior tooth (4b) thin. Anterior

←

length 9.9 mm, JUE no. 15864; Figure 20, hinge length 16.5 mm, JUE no. 15862. Figures 19, 22, 24. Outline of juvenile shells; Figure 19, length 30.8 mm, JUE no. 15867-2; Figure 22, length 40.8 mm, JUE no. 15867-1; Figure 24, length 9.8 mm, JUE no. 15867-8. Figure 21a, b; Figure 21a, dorsal view of holotype, showing external ligament; Figure 21b, lateral view of holotype, length 63.4 mm, JUE no. 15858. Figures 23, 26. Outline of paratype; Figure 23, length 43.6 mm, JUE no. 15860; Figure 26, length 66.7 mm+, JUE no. 15859. Figure 25. Paratype showing the posterior adductor scar and the entire pallial line, length 47.2 mm, JUE no. 15861.

Figure 32. Distribution of *Adulomya* in Japan.

adductor muscle scar ovate and deeply excavated; posterior adductor muscle scar subround. Pallial line entire, starting at base of anterior muscle scar, entire. Interior radial striation absent.

Remarks: From the type locality, Ueda et al. (1995) illustrated some small specimens of this species as *Calyptogena* sp. Amano & Kanno (2005) described *Calyptogena* sp. B from the same locality and from the lower Pliocene Kurokura Formation in Joetsu. Some but not all of these belong to *A. kuroiwaensis*: the identity of two illustrated specimens (*Calyptogena* sp. B of Amano & Kanno, 2005: figs. 7, 10) remains

uncertain because its proportions differ from those of *A. kuroiwaensis*.

Comparison: *Adulomya kuroiwaensis* resembles *A. chinookensis* (Squires & Goedert, 1991), from the upper Eocene seep carbonates of the 'Siltstone of Cliff Point' in Washington State, USA, in size and shell outline. But *A. kuroiwaensis* has a more anteriorly situated beak and a more expanded posterior part than *A. chinookensis*. The Japanese *A. uchimuraensis* and *A. chitanii* have lower shells than *A. kuroiwaensis*. In addition, *A. chitanii* has a pallial sinus, which is lacking in *A. kuroiwaensis*.

Some specimens of *Calyptogena akanudaensis* have

Table 4
Measurements of *A. kuroiwaensis*
sp. nov. from loc. 4.

JUE specimen no.	Type	Length (mm)	Height (mm)	Thickness (mm)
15858	Holotype	63.4	24.8	13.3
15859	Paratype	66.7+	24.6	—
15860	Paratype	43.6	16.7	11.2
15861	Paratype	47.2	22.1	—
15867-1		40.8	17.6	8.4
15867-2		30.8	14.6	8.2
15867-3		23.9	12.1	6.6
15867-4		56.2	19.5	—
15867-5		29.6	13.2	8.4
15867-6		18.4	9.9	5.2
15867-7		13.5	7.1	4.6
15867-8		9.8	5.4	2.9
15868-1		69.3	24.0	—
15868-2		42.1	16.7	—
15868-3		22.0	9.0	—
15868-4		74.9+	26.5	16.1
15868-5		41.7	17.1	—
15868-6		51.3+	18.4	10.7

similar proportions as *A. kuroiwaensis* (compare Figures 23 and 28) but in general, *A. kuroiwaensis* has a more anteriorly situated beak and an expanded posterior part. Only three paratype specimens of *Calyptogena akanudaensis* Tanaka, 1959 are preserved from the type locality (loc. 1 on Figure 1 herein) of the middle Miocene Bessho Formation in Nagano Prefecture. Despite intense subsequent collecting effort at this site, it has not been found again. Three type specimens deposited at the Shinshu-Shinmachi Museum are depicted here (Figures 27–29); they are articulated specimens and thus show no internal features. The identity of this species remains unclear.

Measurements: See Table 4.

Distribution: The uppermost middle or lowest upper Miocene Ogaya Formation.

Paleobathymetry: Based on benthic foraminifers (cf. Ueda et al., 1995), *A. kuroiwaensis* lived in the middle bathyal zone (1000–2000 m depth).

Etymology: After the local name, from where the type specimens were collected.

DISCUSSION

The fossil record of *Adulomya* in Japan includes five well-established species and several uncertain records (Figure 32, Table 5). They show an interesting evolutionary history of an initial radiation and subsequent

decline. The oldest occurrences of *Adulomya* that we are able to confirm are from the early Miocene. A Cretaceous record—as *Calyptogena (Ectenagena)* sp.—is in fact a solemyid (Kiel et al., 2008). Another record that could potentially be older than Miocene is ‘*Calyptogena* cf. *phaseoliformis*’ reported by Ninomiya et al. (2007, 2008) in rocks derived from the Middle Formation of the Taishu Group on Tsushima Island. The absolute age of this formation is 30.5–18.7 Ma (Takahashi & Hayashi, 1985, 1987).

In the North Pacific fossil record, *Adulomya* first appeared in the Late Eocene of the eastern Pacific (Amano & Kiel, 2007). By the early Miocene it had spread to Japan, quite likely along the North Pacific continental slope as suggested by its presence in the early Miocene of Alaska (Kanno, 1971; Kiel & Amano, 2010, and herein). Prior to the arrival of *Adulomya* the only vesicomyid in Japan was the endemic genus *Hubertschenkia* (Amano & Kiel, 2007).

During early and middle Miocene time *Adulomya* had an impressive diversity in Japan, consisting of five species. Most of these species lived at lower sublittoral to middle bathyal depths; only *A. hokkaidoensis* lived in deeper waters. In contrast, the late Miocene to early Pliocene record is confined to only two unconfirmed species: *Adulomya? hachiyai* in Aomori Prefecture and *Adulomya* sp., in Niigata Prefecture. This decline coincides with the appearance of *Archivesica* and *Calyptogena* in Japan: *Calyptogena pacifica* Dall, 1891 from the upper Miocene Morai Formation in Hokkaido and from the upper Miocene Nodani Formation in Niigata Prefecture (Amano & Kanno, 2005), and *Archivesica* cf. *kawamurai* (Kuroda, 1943) from the lower Pliocene Ochiai Formation in Kanagawa Prefecture, central Honshu (Matsushima et al., 2003). From the Pliocene to Recent, both genera are widely distributed in Japan (Majima et al., 2005; Sasaki et al., 2005). Eight species of *Archivesica* and two species of *Calyptogena* live around Japan. Interestingly, the four Japanese species of *Adulomya* live in deeper water (3300–6809 m) than Japanese members of *Archivesica* and *Calyptogena* (Sasaki et al., 2005) as well as the fossil species of *Adulomya*. *Adulomya* might thus have followed an onshore–offshore trend as has been suggested for members of the vent and seep fauna in general (Tunncliffe, 1992; Kiel & Little, 2006).

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Table 5
Doubtful species of *Adulomya* and their statuses.

Species	Reference	Formation	Age	Status	Remarks
<i>Calypptogena</i> (<i>Ectenagena</i>) sp.	Ogasawara et al. (1994); Kuramochi et al. (1999)	Aokiyama Formation	Early Miocene	<i>Adulomya?</i> sp.	Elongate shell having the outline of extant <i>A. kaikoi</i> (Okutani & Métiévier, 1986), up to 98.8 mm long, distinct ridge from beak to posterior corner, other internal features unknown.
<i>Calypptogena</i> ? sp. <i>Calypptogena</i> sp.	Ogasawara et al. (1986) Kanie et al. (1991)	Onnagawa Formation Misaki Formation.	Middle Miocene Middle Miocene	<i>Adulomya?</i> sp. <i>Adulomya?</i> sp.	Elongate shell, internal features unknown. Small, elongate shells (~ 10 mm length) resembling juvenile <i>A. chitani</i> in general shape, internal features unknown.
<i>Calypptogena</i> sp. A	Amano & Kanno (2005)	Nanbayama Formation	Middle Miocene	<i>Adulomya</i> sp.	Elongate shell with two cardinals in right valve; specimens deformed, preventing identification on species level
<i>Solemya</i> (<i>Adulomya</i>)? <i>hachiyai</i> Nomura, 1935	Nomura (1935)	Akaishi Formation	Latest Miocene To Earliest Pliocene	<i>Adulomya?</i> <i>hachiyai</i> (Nomura)	Elongate shell like <i>A. uchimuraensis</i> , up to 190 mm long, no pallial sinus; right valve hinge with two cardinal teeth (Dr. Yukito Kurihara, personal communication). Very similar in size and proportion to <i>A. uchimuraensis</i> .
<i>Calypptogena</i> sp. B	Amano & Kanno (2005)	Kurokura Formation	Early Pliocene	<i>Adulomya</i> sp.	Large, inflated shell which beak located more posteriorly than in <i>A. kuroiwaensis</i> ; internal features unknown.
<i>Adulomya</i> (?) <i>azarie</i> Shikama, 1969	Shikama & Masujima (1969)	Ikego Formation	Pliocene	mytilid?	Large, elongate shell, 117.7 mm long, with expanded posterior part like <i>Gigantidas</i> Cosel & Marshall, 2003; internal features unknown.
<i>Vesicomya ellipsoidea</i> Kanie & Kuramochi, 2001	Kanie & Kuramochi (2001)	Shiramazu Formation	Pliocene	<i>Archivesica</i> or <i>Adulomya</i>	Very large (up to 235 mm), elliptical shell with two cardinals in right valve.

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